SPERRY Microline® MONITOR

SPERRY MICROWAVE ELECTRONICS COMPANY, CLEARWATER, FLORIDA • DIVISION OF SPERRY RAND CORPORATION

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ATTENUATION MEASUREMENT

Attenuation Measurement Equipment. The accurate measurement of attenuation at frequencies greater than 500 mc, particularly over large dynamic ranges, has been difficult to achieve in the typical microwave laboratory. Even more difficult is the output level calibration of standard signal generators because of the low signal power encountered. Most laboratories are equipped to make high accuracy measurements directly over the 30 db range from −10 to −40 dbm. However, there have been no simple, relatively inexpensive devices on the market which could be used in conjunction with standard available components to make attenuation measurements of 100 db or more and to calibrate signal generators at power levels as low as −110 dbm.

The SPERRY Microline 61A1 Microwave Receiver was developed to meet these requirements, i.e., to provide necessary accuracy and dynamic measurement range at a cost within the economic capabilities of the majority of measurement laboratories. The 61A1 is based on the parallel i-f substitution technique for attenuation measurement originated in England by Gainsborough.[1] It differs from other available devices which employ this technique[2,3] in its lower cost and smaller size.

Figure 1. SPERRY Microline 61A1 Microwave Receiver

Substitution Systems. Attenuation measurements are made most accurately by substituting the insertion loss of a calibrated element for that of an unknown element in the test setup. Substitution systems (classified according to the point in the setup at which the substitution is made), include r-f substitution, audio substitution, and i-f substitution. The latter is generally considered to be the most accurate, and may be either series or parallel type. In i-f series substitution systems, the reference attenuator is inserted in series with the test signal path. In parallel substitution systems, the reference attenuator controls the level of a highly stable i-f reference oscillator which is compared with the level of the i-f test signal. A description of this technique as instrumented in the 61A1 is provided in this issue.

Following the description of the 61A1 is an analysis of the dynamic range and accuracy of the instrument. The analysis is of significance not only because it defines the inherent accuracy of the 61A1, but also because it permits selection of the optimum operating point for a particular measurement to achieve maximum accuracy.

MODEL 61A1 MICROWAVE RECEIVER

General Description. A block diagram of the SPERRY Microline 61A1 Microwave Receiver is shown in figure 2. The microwave test signal and the local oscillator signal are combined in a linear-response mixer to produce a 30 mc i-f output which varies with changes in the level of the microwave test signal. The i-f test signal is 100% amplitude modulated either by the diode switch or by modulating the microwave signal source. The modulated i-f test signal is combined with the *parallel* 30 mc reference signal at the input to the i-f amplifier. An ultrastable crystal-controlled oscillator generates the 30 mc reference signal which is amplitude modulated 180 degrees out of phase with the test signal. The level of the reference signal is accurately controlled by the 30 mc standard attenuator. In effect, the i-f amplifier input is switched alternately between the i-f test signal and the 30 mc reference signal at a 1000 cycle rate.

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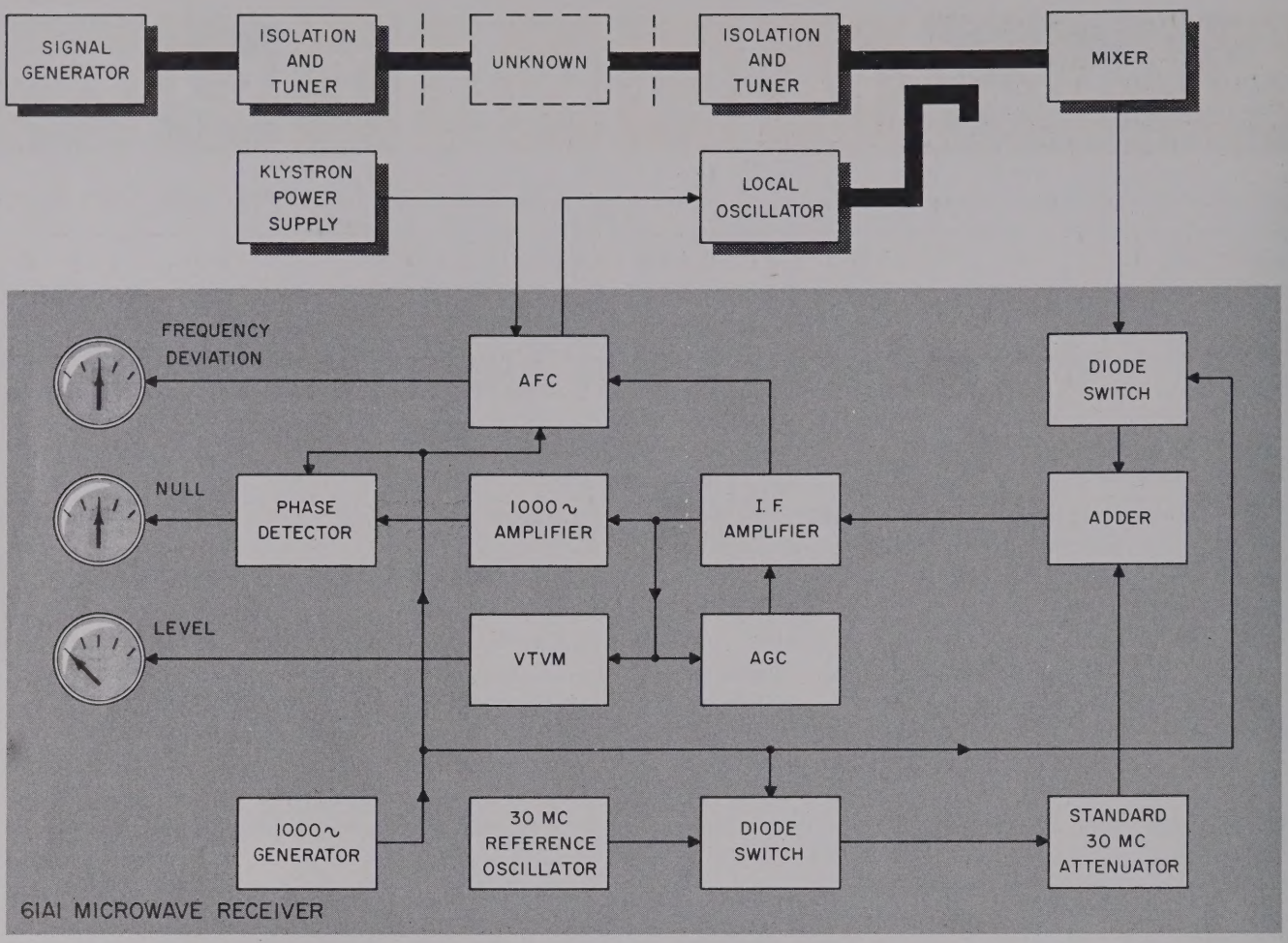

Figure 2. *Microline* **61A1 Microwave Receiver, Block Diagram**

The i-f amplifier, 1000 cycle amplifier, and phase detector function as a null indicating system which indicates equality of the i-f test and reference signals. Measurements are made by noting the standard attenuator readings for null indications *before and after* the level of the microwave signal is changed by insertion of the unknown. The null indicating system is capable of resolving very small differences between the test and reference signals. Since equivalence of the two signals is the significant criterion, the measurement is not affected by nonlinearity in the response of the i-f amplifier. The effect of frequency drift of the microwave signal generator or local oscillator on measurement accuracy is minimized by high performance AFC circuitry.

The chief advantage of the parallel i-f substitution technique is that a greater dynamic range is obtained because much smaller signal powers can be utilized. In a series substitution system, the minimum useful signal power is limited by the insertion loss in the 30 mc standard attenuator; if a preamplifier is used to compensate for this insertion loss, the dynamic range is further limited to the linear range of the preamplifier (typically 40 db for 0.1 db accuracy). Parallel substitution imposes none of these limitations on minimum detectable signal and, in fact, the coherent phase detector provides an additional improvement in usable signal-to-noise ratio.

The 61A1 Microwave Receiver is also extremely useful in making absolute power measurements at signal levels as low as —110 dbm. An absolute power calibration is obtained by using an accurately known microwave signal power (e.g. 1 mw) in setting the initial reference null.

Figure 3 shows a typical setup using the 61A1 to calibrate an X-band signal generator.

DESCRIPTION OF MAJOR ELEMENTS IN THE 61A1 MICROWAVE RECEIVER

Microwave Circuitry. The *amplitude stability* of the microwave signal source and of the local oscillator, to a more limited extent, is critical to the measurement accuracy. Any change in the level of the microwave signal during a measurement appears as a direct error. For the majority of measurements, klystrons with water jacket cooling* have proven sufficiently stable.

*MICROLINE MONITOR, April 1961

Figure 3. Signal Generator Calibration Using the 61A1

However, when stabilized klystrons cannot be used or in cases where even greater stability is required, a second mixer may be incorporated in the microwave circuitry to reduce errors due to source instability. As shown in figure 4, the second mixer is coupled to the signal source ahead of the unknown. The 30 mc i-f output of the second mixer is amplified and used as a comparison reference signal, replacing the signal from the 30 mc reference oscillator. Thus, any changes in the level of the signal generator will affect the test and reference signals equally. The local oscillator is common to both mixers to assure that the i-f reference and test signals are at the same frequency. Isolators in the interconnecting local oscillator arm eliminate signal leakage through the local oscillator coupling loop.

Necessary precautions in *transmission line matching and isolation* must be observed to achieve the full accuracy capabilities of the system, as discussed in the literature.[4] Adequate care must be taken to avoid errors due to leakage in the microwave circuitry.

The required *waveguide or coaxial components* are all standard Microline catalog items. Table 1 page 8 lists the recommended Microline local oscillator couplers and single-ended mixers, along with available frequency ranges.

Signal Switching. The i-f test signal is 100% amplitude modulated either by modulating the signal source or by an internal (diode) switching arrangement, depending upon the signal powers involved. The internal switching operates for measurements of dynamic ranges up to 70 db, and offers not only added convenience but permits use of the 61A1 with almost any type of microwave source.

The internal diode switches are used to alternate the 30 mc input to the i-f amplifier between the test and reference signals for *signal powers greater than –80 dbm.* One diode is placed in the test signal input channel and the other in the reference signal channel ahead of the standard attenuator. The diode circuit polarities are arranged 180 degrees apart so the 1000 cycle modulating signal simultaneously closes one circuit and opens the other.

For *measurements below –80 dbm,* the diode switch in the test signal channel is disabled and the 1000 cycle modulation is applied directly to the microwave signal source. This arrangement prevents

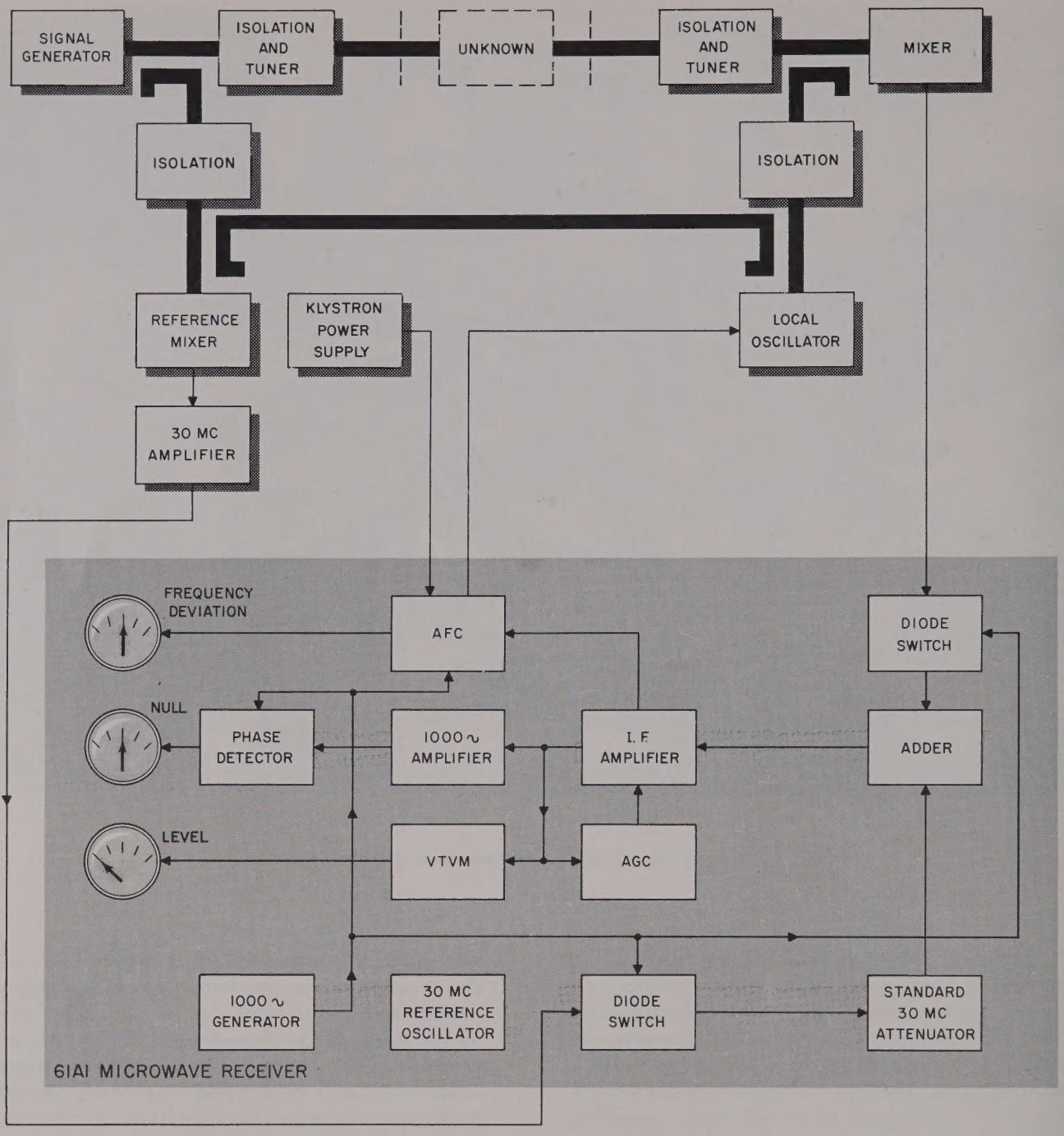

Figure 4. Dual Channel Parallel I-f Substitution System

the appearance of a coherent 1000 cycle component in the noise input—since the input diode switch would modulate the mixer noise. Introduction of such a coherent noise component would become increasingly significant at small signal-to-noise ratios. However, with the input diode switch disabled and the microwave signal source modulated rather than the i-f test signal, the i-f noise input remains constant and only the test signal carries the coherent 1000 cycle modulation.

Reference Oscillator. Among the factors that contribute significantly to the measurement accuracy of the Microline 61A1 Microwave Receiver are the amplitude and frequency stability and shielding of the 30 mc reference oscillator. To assure maximum stability, the oscillator is crystal controlled and transistorized. Signal leakage to the high gain i-f amplifier is prevented by completely enclosing the reference oscillator in a specially constructed brass shield, thereby assuring that all the reference signal is passed through the 30 mc attenuator. The i-f diode input switch and the adder circuitry are also enclosed in a similar shield. Double shielded cable is used where necessary throughout the instrument.

Standard Attenuator. To provide maximum utility per instrument dollar, the standard 30 mc attenu-

ator in the 61A1 is one of moderate accuracy. It utilizes a 0.5000-inch-diameter waveguide below cutoff and a precision lead screw drive. Accuracy is 0.05 db per 10 db for a 100 db dynamic range; readout least division is 0.02 db.

The attenuator with indicator can be removed easily for NBS or other special calibration, or for replacement should ultra precise 30 mc standards be required.

Null Indicating System. The i-f amplifier, 1000 cycle amplifier, and phase detector function as a null indicating system. The i-f amplifier input is alternately the test signal output of the mixer and the reference signal output of the standard attenuator. Input switching and adding circuitry are tuned for optimum noise figure; tuning is not affected by signal switching.

The i-f amplifier consists of a cascode input amplifier followed by three synchronously tuned, high gain stages and an a-m detector. For AFC, a limiter stage and f-m detector are also provided. The noise figure of the amplifier is less than 1.5 db and bandwidth is approximately 1 mc, with a smooth bandpass. Amplifier gain is adjustable over a 100 db range. Neither the bandpass nor the tuning are affected by changes in gain. The 100 db gain variation is achieved by controlling the gain of two stages and minimizing stage-to-stage coupling in the design. Gain may be adjusted manually or controlled by AGC circuitry either for constant output level or for logarithmic response. The constant output AGC is generally used for attenuation measurement to provide constant null sensitivity for all input signal levels.

The output of the a-m detector is amplified by a 1000 cycle amplifier with a 30 cycle bandwidth. The amplified 1000 cycle signal is phase detected by comparison with the 1000 cycle signal from the modulator. Phase detector output is displayed on a *null* (zero center scale) meter. With AGC, each division on the *null* meter scale represents 0.02 db difference between the test and reference signals.

A VTVM and associated *level* indicator are provided for normal microwave receiver applications of the 61A1.

Automatic Frequency Control. AFC circuitry minimizes the effect on measurement accuracy of frequency drift in the microwave signal generator or local oscillator. It is adaptable to frequency control of several types of local oscillators, including kylstrons and BWO's.

The i-f amplifier alternately sees the test and reference signals being compared. Any difference in frequency between the two signals results in an audio signal from the f-m detector at the comparison rate. The phase of the signal indicates the polarity of correction required. This frequency error signal is applied to a phase detector in the AFC section. The AFC correction is independent of the discriminator center frequency and the incoming signal is locked to the frequency of the reference oscillator. The amount of error involved in null operation depends to some extent on the frequency relationship of the two signals to each other and to the i-f passband. If the frequencies are different, their response will vary, depending on where they are located on the i-f response curve. If the frequencies are the same, their response will be the same, regardless of where they fall on the i-f response curve.

When the 61A1 is used as a *conventional receiver*, the phase sensitive AFC signal is generated by applying the output of the i-f discriminator to a phase modulator driven at the normal comparison rate. AFC operation is the same as for automatic null operation except that the AFC is now centered on the center frequency of the discriminator.

SUMMARY

The *Microline* 61A1 Microwave Receiver employs the parallel i-f substitution technique of attenuation measurement. The lower cost and smaller size of the 61A1, compared to other instruments of this type, place it within the financial reach of most microwave laboratories. The i-f and comparison components necessary to make the attenuation measurements are an integral part of the 61A1 while accessory waveguide and coaxial components are all standard *Microline* items.

The 61A1 can also be used for normal receiver applications such as antenna pattern and noise figure measurements, or as an ultra-sensitive microwave detector.

FEATURES

- 100 db single step attenuation measurement range
- Precision cutoff attenuator accurate to 0.05 db per 10 db
- Linear, log or AGC operation
- Source frequency drift compensated by high performance AFC circuitry
- I-f noise figure of 1.5 db
- Overall receiver noise figure of 3 db
- −110 dbm measurement sensitivity

DYNAMIC RANGE AND ACCURACY ANALYSIS

Factors Affecting Measurement Range and Accuracy. Three fundamental factors affect the inherent range of measurement and the measurement accuracy of the *Microline* 61A1 Microwave Receiver. These are:

- Nonlinearity of the mixer for large signals
- Noise errors for small signals
- Range and accuracy of the standard attenuator.

While other factors can affect the measurement accuracy, the design approach of the 61A1 has reduced these to insignificant levels. In this category are instability of the microwave source, finite frequency differences between the i-f test and reference signals, reference signal leakage, etc.

Analysis of Measurement Accuracy over Signal Power Extremes. The following analysis is independent of standard attenuator range and accuracy.

The analysis to predict the accuracy of measurement over the extremes of signal power assumes that the mixer is perfectly linear for very small signals and that mixer linearity is a problem only for signal levels at which noise uncertainties can be ignored. The results of the analysis substantiate this assumption and indicate a considerable range over which neither factor contributes significant uncertainty.

In considering mixer non-linearity, the method of analysis used by Weinschel et al[2] has been used as a first approximation. (See page 7.) Figure 5a is a plot of the calculated nonlinearity of the mixer. From this data it is possible to evaluate the expected mixer nonlinearity errors for typical measurements. Using 1 mw of local oscillator power, the error contribution is less than 0.12 db for signal powers less than −10 dbm and less than 0.012 db for signal powers less than −20 dbm.

resulting in undesirable narrow band limitations and excessive cost. Consequently, an overall noise figure of 10 db is considered representative of typical single-ended mixer performance for the remainder of this discussion.

The *equivalent input noise power* for the 61A1 Microwave Receiver is:

$$P_n \cong \overline{V}_n^2 = NKT\,\Delta F = 4.14 \times 10^{-14} \text{ watts} = -104 \text{ dbm} \qquad (1)$$

where

N = receiver noise figure = 10 db
K = Boltzman constant = 1.38×10^{-23} watt/cycle/°K
T = absolute temperature = 300°K
ΔF = i-f bandwidth = 10^6 cps.

The *total signal applied to the second detector is:*

$$\overline{V}^2 = G(\overline{E}_{sig}^2 + \overline{V}_n^2) \qquad (2)$$

where G = amplifier gain.

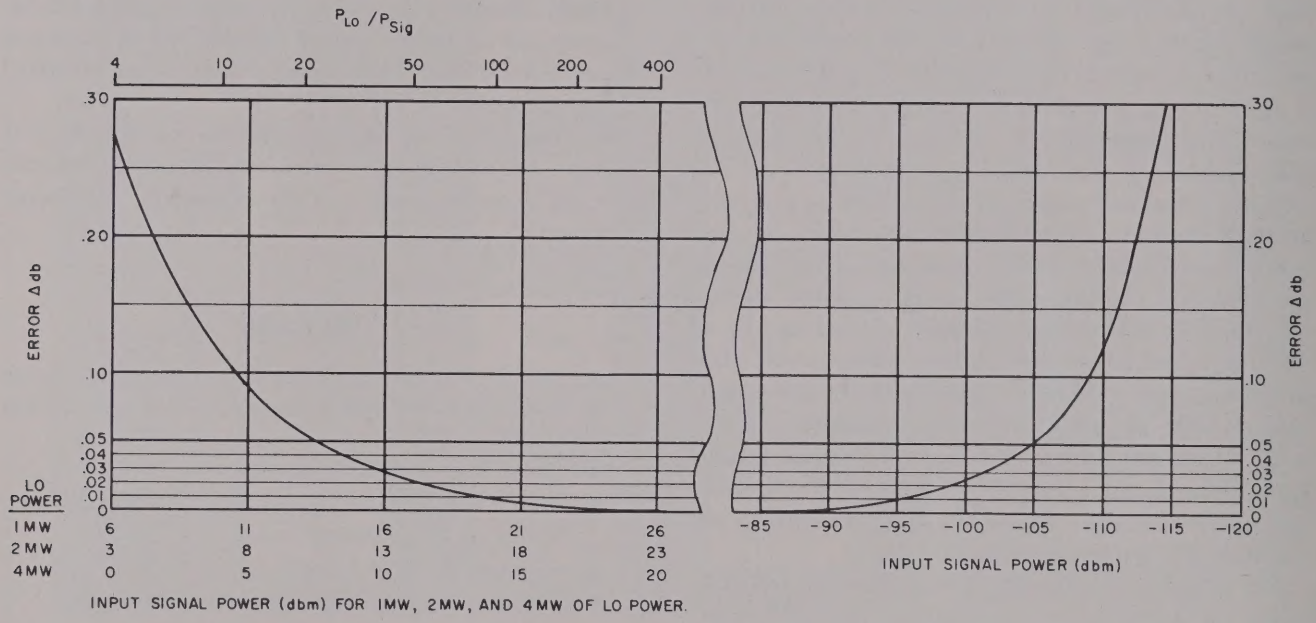

Figure 5a. Error Due to Mixer Nonlinearity

Figure 5b. System Error Due to Noise

Increasing the local oscillator power above the optimum value for minimum discernible signals will increase the maximum usable signal by the same ratio that the local oscillator power is increased. Since the noise figure of the crystal mixer increases less rapidly as local oscillator drive is increased, the overall dynamic range of measurement increases with local oscillator power. The limit is determined by limits on local oscillator and crystal power.

On the *small signal end of the measurement range,* the measurement accuracy is affected by noise generated in the crystal mixer, i-f amplifier, and local oscillator. Numerous techniques are available for reducing the effective noise. For a general purpose laboratory instrument, however, a significant noise figure improvement cannot be accomplished without

If we let E_1 = the test signal input, and E_2 = the reference signal input, then the *1000 cycle output signal from the second detector is:*

$$V_{ac} = \sqrt{G(\overline{E}_1^2 + \overline{V}_n^2)} - \sqrt{G(\overline{E}_2^2 + \overline{V}_n^2)} \quad . \qquad (3)$$

The *noise-to-signal ratio* (voltage) at the phase detector input can now be represented as:

$$\rho_i = \frac{V_n\sqrt{\alpha G}}{V_{ac}} = \frac{V_n\sqrt{\alpha}}{\sqrt{\overline{E}_1^2 + \overline{V}_n^2} - \sqrt{\overline{E}_2^2 + \overline{V}_n^2}} \qquad (4)$$

where α, the reduction in equivalent noise input as a result of the 30 cycle bandwidth of the 1000 cycle amplifier, is:

$$\alpha = \sqrt{\frac{\Delta F_2}{\Delta F_1}} = \sqrt{\frac{30}{10^6}} = 54.8 \times 10^{-4} .$$

Let $\bar{E}_1^2 = r\bar{E}_2^2$, and $\bar{V}_n^2 = R\bar{E}_2^2$ for $r \cong 1$, and

substituting in equation (4):

$$\rho_i = \frac{.074\sqrt{R}}{\sqrt{r + R} - \sqrt{1 + R}} . \qquad (5)$$

Since the phase detector is in effect a device which performs the operation of cross-correlating the 1000 cycle square wave which results from switching between test and reference signal inputs with a clean 1000 cycle signal, the *relationship between the input and output signal-to-noise ratio of the phase detector* as given by Lee[5] is:

$$\frac{S}{N}(\text{output}) = 10 \log_{10} \frac{n}{1 + 2\rho_i^2} \qquad (6)$$

where n = number of cycles averaged = 1000.

If we make the conservative assumption that the operator of the 61A1 can observe an unbalance on the *null* meter when the phase detector output signal is equal to or greater than the noise (i.e. $\frac{S}{N}$ (output) = 0 db), then:

$$0 \text{ db} = 10 \log_{10} \frac{1000}{1 + 2\rho_i^2}$$

$$\rho_i = 22.35$$

Substituting $\rho_i = 22.35$ in equation (5) and solving for r we get:

$$r = 1 + 0.00662\sqrt{R(1 + R)} + 0.000011\sqrt{R} \quad . (7)$$

Since $r = \frac{\bar{E}_1^2}{\bar{E}_2^2}$, the amount that this ratio differs from unity represents the *error due to noise in establishing equivalence of the test and reference signals.*

Equation (7) has been solved for this error (r) for various values of input noise-to-signal ratio (R). The results are plotted in figure 5b. The effect of receiver noise figures better than the assumed 10 db is determined by shifting the signal power scale to the left by the amount of the improvement.

Figures 5a and 5b show that for a measurement of 100 db, the *total uncertainty due to noise and mixer nonlinearity* is 0.3 db using a 1 mw local oscillator level. Considering the accuracy of the standard attenuator included in the Microline 61A1 Microwave Receiver, the total uncertainty for this measurement should be less than 0.5 db. This uncertainty can be reduced significantly by using higher local oscillator power, by reducing the mixer noise figure, and by the use of an ultra precise standard attenuator. The total uncertainty due to noise and mixer nonlinearity is less than 0.01 db over the 55 db range from −25 dbm to −80 dbm.

Figures 5a and 5b are also extremely useful for determining the *initial local oscillator-to-signal ratio* to minimize the uncertainty for various measurement ranges.

The specifications for the Microline 61A1 Microwave Receiver are given on page 8. It is apparent from the foregoing analysis that the accuracy specifications can be easily realized in typical applications.

By Paul C. Ely, Jr.
Harry F. Strenglein

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CALCULATION OF MIXER NONLINEARITY

The i-f output is taken as the vector difference between the local oscillator and signal voltages.

$$e_{IF} = \left[E_{LO}^2 + E_{sig}^2 - 2E_{sig} E_{LO} \cos \omega_{IF} T \right]^{1/2} \qquad (1)$$

Expanding this in a Fourier series,

$$e_{IF} = a_0 + a_1 \cos \omega_{IF} T + a_2 \cos 2\omega_{IF} T \ldots \qquad (2)$$

where

$$a_n = \frac{1}{\pi} \int_0^{2\pi} \left[E_{LO}^2 + E_{sig}^2 - 2E_{Log} E_{sig} \cos\omega_{IF} T \right]^{1/2} \times \cos n\omega_{IF} T \, d(\omega_{IF} T) \qquad (3)$$

Since we are concerned solely with the fundamental i-f component, only a_1 is of interest. Performing the above integration and making the substitution

$$r = \frac{E_{sig}}{E_{LO}},$$

$$a = \frac{2E_{sig}}{(1 + r^2)^{1/2}} \left[1/2 + 3/16 \frac{r^2}{(1 + r^2)^2} + \frac{14r^4}{53(1 + r^2)^4} + \frac{33 \times 105 r^6}{16\,384\,(1 + r^2)^6} \right] \ldots \qquad (4)$$

With E_{LO} constant, a_1 would be linearly proportional to r if the system were perfectly linear. The change in ratio between them is the system nonlinearity and has been calculated from equation (4). The results are expressed in db and are plotted in figure 5a.

TABLE I

Microline Local Oscillator Couplers and Single Ended Mixers Recommended for Use with 61A1 Microline Receiver

LOCAL OSCILLATOR COUPLERS				TUNABLE MIXERS		
Model	Frequency (Gc)	Average Coupling (db)	Price	Model	Frequency (Gc)	Price
45S1	2.60- 3.95	3, 10, 20	$375	34S1	2.60- 3.95	$180
45C1	3.95- 5.85	3, 10, 20	$250	34C1	3.95- 5.85	$ 95
45G1	5.85- 8.20	3, 10, 20	$140	34G1	5.85- 8.20	$ 90
45H1	7.05-10.00	3, 10, 20	$120	34H1	7.05-10.00	$ 85
45X1	8.20-12.40	3, 10, 20	$100	34X1	8.20-12.40	$ 75
45U1	12.40-18.00	3, 10, 20	$115	34U1	12.40-18.00	$160
45K1	18.00-26.50	3, 10, 20	$175	34K1	18.00-26.50	$170
45V1	26.50-40.00	3, 10, 20	$200	34V1	26.50-40.00	$180
				34B2*	1.00- 6.00	$210
				34B3*	0.30- 2.00	$210

*Includes L. O. Couplers

SPECIFICATIONS

Realizable Accuracy: Over 100 db range in one step: ±0.5 db
Over 50 db range in one step: ±0.2 db

Input level to mixer	Maximum Error
−10 to −25 dbm	0.12 db/10 db
−25 to −80 dbm	0.06 db/10 db
−80 to −95 dbm	0.12 db/10 db*
−95 to −110 dbm	0.2 db/10 db*

*With external signal modulation

Null resolution: 0.008 db per division to −95 dbm
0.05 db per division to −110 dbm

I-f Amplifier

Center frequency	30 mc
Bandwidth (3 db points)	1 mc
Noise figure	1.5 db or better
Output	0 - 30 volts linear to 3% 60 db log (0 - 30 volt range) to 3% AGC, approximately 2 volt output
Overall effective noise figure (including input switch)	3 db or better
Gain variation	In excess of 100 db

Reference Oscillator

Crystal-controlled oscillator, 30 mc ±0.02%
30 mc output signal available at rear of chassis

Comparison Setup

Switching rate	1 kc
Signal switching	Internal or external—1 kc square wave output at rear of chassis

30 mc Attenuator

0 to 100 db indication with in-line readout (least division 0.02 db)
"0" insertion loss approximately 25 db
Accuracy: 0.05 db/10 db

Outputs

A-c video on front panel
D-c video on rear of chassis
Recorder jack on output VTVM, 0 to 1 ma, 1500 ohms, one side ground

Metering

Output Level Indicator

D-c video ranges; 1, 3, 10, & 30 volts full scale
Log d-c video; 0-60 db range, 30 volts full scale
A-c video; 30 volts full scale.
Mixer crystal current; 3 ma full scale, positive or negative polarity

Frequency deviation indicator: center zero

Null indicator: center zero 0.008 db per division

AFC UNIT

Correction voltage range: ±25 volts centered on input reflector voltage.
Control current: 0 to 20 ma either polarity.
Sense: selected + or − from panel
Insulation: 5000 volts for beam plus reflector.
AFC Center Frequency: Locked to reference oscillator frequency for comparison mode.
Locked to discriminator center frequency for standard receiver mode.

Power

105 - 125/210 - 250 volt, 50 - 60 cps line
Approximately 150 watts

Weight

55 pounds, including case

Size

12½ x 18 x 19 inches

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